USAAEFA PROJECT NO. 77-25

PRELIMINARY AIRWORTHINESS EVALUATION AH-1S HELICOPTER WITH OGEE TIP SHAPE ROTOR BLADES

FINAL REPORT

GARY L. BENDER
PROJECT OFFICER

RALPH WORATSCHEK
PROJECT ENGINEER

DAVID OTTOMEYER
PROJECT ENGINEER

HENRY ARNAIZ
PROJECT ENGINEER

LARRY HIGGINS
MAJ, INF
US ARMY
PROJECT PILOT

JOHN S. TULLOCH
CW4, USA
PROJECT PILOT

MAY 1980

UNITED STATES ARMY AVIATION ENGINEERING FLIGHT ACTIVITY
EDWARDS AIR FORCE BASE, CALIFORNIA 93523

DISCLAIMER NOTICE

The findings of this report are not to be construed as an official Department of the Army position unless so designated by other authorised documents.

DISPOSITION INSTRUCTIONS

Destroy this report when it is no longer needed. Do not return it to the originator.

TRADE NAMES

The use of trade names in this report does not constitute an official endorsement or approval of the use of the commercial hardware and software.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER USAAEFA Report No. 77-25	2. GOVT ACCESSION NO. AD-A089	3. RECIPIENT'S CATALOG NUMBER 625
4. TITLE (and Subtitle) (6) PRELIMINARY AIRWORTHINESS EVALUATION AH-1S HELICOPTER WITH OGEE TIP SHAPE ROTOR BLADES		5. TYPE OF REPORT & PERIOD COVERED (9) FINAL REPORT NOV 79-APR 80
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) GARY L. BENDER, RALPH WORATSCHEK, HENRY ARNAIZ, MAJ LARRY HIGGINS, DAVID OTTOMEYER, ~~CW4 JOHN S. TULLOCH~~		8. CONTRACT OR GRANT NUMBER(s) (11) May 80
9. PERFORMING ORGANIZATION NAME AND ADDRESS US ARMY AVIATION ENGINEERING FLIGHT ACTIVITY EDWARDS AFB, CA 93523		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS ET-9-RT028-01-ET-EG (12) 48
11. CONTROLLING OFFICE NAME AND ADDRESS US ARMY AVIATION ENGINEERING FLIGHT ACTIVITY EDWARDS AFB, CA 93523		12. REPORT DATE MAY 1980
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (14) USAAEFA-77-25		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

AH-1S Helicopter
Hover Performance
K747 Rotor Blades
Level Flight Performance
Low-speed Flight Characteristics
OGEE Tip Shape Rotor Blades

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The United States Army Aviation Engineering Flight Activity conducted a Preliminary Airworthiness Evaluation of the AH-1S helicopter with OGEE tip-shape main rotor blades to determine if any improvement in performance or handling qualities resulted from replacing the K747 blades. Additionally, the acoustics signature of the OGEE blades were measured by the US Army Research and Technology Laboratories (Aeromechanics Lab). Tests were conducted at Edwards Air Force Base (elevation 2302 feet) and Coyote Flats (elevation 9980 feet), California from 1 November 1979 through 8 April 1980. Forty-five test flights were flown for a total of 36.6 productive hours (63.2 total hours). Both hover and level flight performance were degraded by installation of OGEE tip-shape → over

DD FORM 1473, 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

409025 slt

main rotor blades. Low-speed handling qualities were unaffected by the OGEE blades. Other handling qualities tests were not accomplished. Results of acoustics tests will be reported by the laboratories under a separate cover.

DEPARTMENT OF THE ARMY
HQ, US ARMY AVIATION RESEARCH AND DEVELOPMENT COMMAND
4300 GOODFELLOW BOULEVARD, ST. LOUIS, MO 63120

DRDAV-DI

14 JUL 1980

SUBJECT: Directorate for Development and Qualification Position on the Final Report of USAAEFA Project No. 77-25, Preliminary Airworthiness Evaluation, AH-1S Helicopter with Ogee Tip Rotor Blades

SEE DISTRIBUTION

1. The purpose of this letter is to establish the Directorate for Development and Qualification position on the subject report. The evaluation was conducted as a research and development effort to evaluate performance, handling qualities, and acoustics characteristics of an AH-1S helicopter configured with Kaman K747 rotor blades modified with an Ogee tip shape.

2. This Directorate agrees with the report findings and conclusions. Based on the test results, the AH-1S with the modified Kaman K747 rotor blades exhibited degraded performance and handling qualities characteristics.

FOR THE COMMANDER:

CHARLES C. CRAWFORD, JR.
Director of Development
and Qualification

Accession For
NTIS GRA&I
DDC TAB
Unannounced
Justification
By
Distribution/
Availability Codes
Dist | Avail and/or special
A

AH-1S Equipped with Kaman K747 Rotor Blades

TABLE OF CONTENTS

INTRODUCTION

BACKGROUND

1. The U.S. Army and the National Aeronautics and Space Administration (NASA) are engaged in an effort to develop rotor blades which will improve the acoustic signature, vibratory loads, and performance of helicopters. Various rotor tip planforms have been investigated for that purpose. To evaluate the potential improvements on an AH-1 helicopter, two Kaman K747 main rotor blades have been fabricated with an OGEE tip shape. Kaman Aerospace Corporation conducted initial testing of OGEE tip rotor blades to obtain flight loads measurements prior to government testing. The U.S. Army Aviation Research and Development Command (AVRADCOM) requested that the U.S. Army Aviation Engineering Flight Activity (USAAEFA) conduct a preliminary airworthiness evaluation (PAE) of an AH-1S helicopter with OGEE tip main rotor blades (Ref 1, App A). A test plan (Ref 2) was prepared by USAAEFA and approved by AVRADCOM (Ref 3).

TEST OBJECTIVES

2. The objectives of the test were as follows:

a. To compare the hover and level flight performance of the OGEE tip rotor blades to the performance of the K747 rotor blades.

b. To gather sufficient data to allow the US Army Research and Technology Laboratories (Aeromechanics Lab) to compare the acoustics signature of the K747 and the OGEE tip blades.

c. Compare the handling qualities of the AH-1S with OGEE blades to the handling qualities with K747 blades.

DESCRIPTION

3. The production AH-1S is a tandem seat, two-place helicopter with a two-bladed main rotor and a two-bladed Model 212 tractor tail rotor. The helicopter is powered by a Lycoming T53-L-703 turboshaft engine derated from 1800 shaft horsepower (SHP) at sea-level, standard-day conditions to 1290 SHP for 30 minutes and 1134 SHP for continuous operation of the main transmission. Distinctive features of the helicopter include the narrow fuselage, stub wings with four stores stations and a flat-plate canopy. A more complete description of the AH-1S is presented in the operator's manual (Ref 4). Items affecting aerodynamic drag are documented in Appendix B.

4. The Kaman K747 rotor blade incorporates an advanced design airfoil, a tapered tip planform, composite material construction, and a multicell ballistically tolerant spar. The blades are designed to be individually interchangeable and when used as a set, may be used to replace the standard AH-1 main rotor blades (B540). A complete description of the K747 blade is contained in Reference 5.

5. The OGEE tip rotor blade is a Kaman K747 blade with the tip modified to the OGEE shape. In order to quickly and economically make this modification, the K747 tip weights were left out of the OGEE configuration. This resulted in a low inertia rotor by comparison to either K747 or B540 blades, rotor/engine fuel control matching which was not optimized, and rotor and aircraft dynamic stability which was not representative of a possible future production configuration of OGEE blades. Therefore, most handling qualities tests in Reference 2 were deleted by the Reference 6 message.

TEST SCOPE

6. This PAE was conducted at Coyote Flats, California (elevation 9980 feet) and Edwards Air Force Base, California (elevation 2302 feet) from 1 November 1979 through 8 April 1980. Forty-five tests flights were flown for a total of 36.6 productive test hours (63.2 total flight hours). Flight restrictions contained in the operator's manual (Ref 4, App A) and the airworthiness release (Ref 7) were observed during the tests. Tests were conducted primarily with the OGEE blades installed. Some comparison flights were made with the K747 blades installed. Additional flights were made in support of the Aeromachanics Lab to gather acoustics data. Results of those acoustics measurements will by reported by the Aeromechanics Lab under a separate cover. Test conditions are shown in Table 1.

Table 1. Test Conditions[1]

Type of Test	Avg Gross Weight (lb)	Avg Long CG (FS)	Avg Density Altitude (ft)	Avg OAT (°C)	Avg Rotor Speed (RPM)	Thrust Coefficient	Rotor Blades
Hover performance[2]	7300 to 8060	196.0	10000	-3.5 to 8.0	300 to 325	0.003720 to 0.006750	OGEE
			400	-2.0			
Level Flight Performance[3]	8280	195.1	6000	10.0	321	0.004959	OGEE
	8680	193.6	6580	6.5	319	0.005358	
	8860	194.0	10320	1.0	315	0.006299	
	8700	194.2	8980	-1.5	314	0.005969	K747
Low-speed flight	8480	195.0	10520	2.5	324	N/A	OGEE

Notes: [1] All tests were flown in clean wing configuration.
[2] Hover performance tests were flown out-of-ground effect using the tether technique while varying main rotor speed.
[3] Level flight performance tests were flown at a constant referred main rotor speed of 324 RPM.
[4] Average thrust coefficient. Thrust coefficient varied with fuel burn off during flight.

TEST METHODOLOGY

7. The flight test techniques and data reduction procedures used during this evaluation are described in Appendix D or the appropriate Results and Discussions section of this report. Data were obtained from instrumentation displayed on the pilot and copilot/engineer panels and recorded on magnetic tape. The on-board data acquisition system is further described in Appendix C.

RESULTS AND DISCUSSIONS

GENERAL

8. A PAE of the AH-1S helicopter was conducted to determine any differences in performance or handling qualities caused by the OGEE main rotor blades. Both hover and level flight performance was degraded by installation of the OGEE blades. Except for low-speed characteristics (which were unchanged) the handling qualities were not evaluated.

PERFORMANCE

Hover Performance

9. Out-of-ground effect (OGE) hover performance testing was accomplished with OGEE blades at 9980-foot and 2302-foot elevations using the tethered hover method. With K747 blades, limited hover testing was conducted at the 2302-foot elevation site to verify the performance data presented in Reference 8, Appendix A. This data fell within the scatter of the data presented in Reference 8. Results of the hover performance testing is presented in Figures 1 and 2, Appendix E.

10. Figure 1 presents the hover capability of the AH-1S on a standard day and on a 35°C day with K747 and OGEE blades. It is apparent that the hover performance is degraded by OGEE shaped blade tips. At a pressure altitude of 4000 feet with an air temperature of 35°C, the AH-1S with the OGEE blades can hover at 9056 pounds, gross weight. This represents a reduction of 315 pounds (3.5%) when compared to the K747 performance. At 10,000 feet on a standard day, the degradation is 528 pounds (5.5%).

Level Flight Performance

11. Level flight performance testing was conducted with both K747 and OGEE blades, using the test methods described in Appendix D. Figures 3 through 9, Appendix E, present the level flight performance data.

12. A nondimensional summary of the level flight performance with OGEE blades is presented in Figures 3 through 5. Figures 6 through 8 present the test data from which the summary was derived. Figure 9 presents data gathered with the K747 blades and for comparative purposes, two curves are shown. One curve (derived from Ref 8, App A) is representative of the K747 data gathered during the program. The other is derived from Figures 3 through 5, Appendix E and represents AH-1S level flight performance with OGEE blades installed. At these conditions, an 8-knot reduction in maximum level flight speed resulted from the OGEE tip installation.

13. It should be noted that data gathered during this program with K747 blades indicate an increase in airframe drag when compared to results from Reference 8, Appendix A. The drag change was approximately 2.5 square feet of equivalent flat plate area. A portion of the drag could be attributed to the main rotor mast extension installed to accommodate instrumentation slip rings and to the associated strain gages and wiring on the hub for the OGEE test program. The rest of the drag change could be explained by a change in aircraft pitch attitude. During these tests the aircraft flew in a more nose down pitch attitude than it did at similar

conditions during Reference 8 tests. The aircraft tail boom was replaced between the tests of Reference 8 and the current tests. Although the elevator was rigged properly for both tests, other differences in the tail booms may have resulted in the change in aircraft flight attitude.

HANDLING QUALITIES

Low-speed Flight Characteristics

14. The low-speed flight characteristics of the AH-1S with OGEE blades installed were evaluated at the conditions listed in Table 1. Testing was performed to 30 knots true airspeed (KTAS) rearward, 35 KTAS forward, 35 KTAS in left sideward flight and 12 KTAS in right sideward flight. A ground pace vehicle was used as a speed reference. Surface wind conditions were 5 knots or less. Tests were flown in ground effect at a 10-foot skid height. The low-speed flight data are presented in Figures 10 and 11, Appendix E.

15. Longitudinal and lateral control margins were adequate at all test conditions. Directional control margin was less than 10% in right sideward flight. Inadequate directional control margin at high gross weights and high density altitudes, a previously documented shortcoming of the AH-1S series aircraft, still exists. The problem is slightly worse with OGEE blades because of the increased power required to hover (and therefore increased anti-torque tail rotor thrust requirements).

16. A directional control trim shift of more than 2 inches occurs between 10 and 20 KTAS in left sideward flight. This trim shift will make hovering in gusty left crosswinds difficult. This trim shift is a characteristic of AH-1 aircraft and is not caused by the OGEE main rotor blades.

CONCLUSIONS

17. Both hover and level flight performance of the AH-1S are degraded by installation of OGEE main rotor blades (paras 9 and 11).

RECOMMENDATIOMS

18. None.

APPENDIX A. REFERENCES

1. Letter, U.S. Army Aviation Research and Development Command (AVRADCOM), DRDAV-EQI, 8 June 1979, subject: *Preliminary Airworthiness Evaluation of the AH-1 Advanced (OGEE) Tip Shape Rotor Blades.*

2. Test Plan, U.S. Army Aviation Engineering Flight Activity (USAAEFA), Project 77-25, *Preliminary Airworthiness Evaluation of the AH-1 Advanced (OGEE) Tip Shape Rotor Blades,* July 1979.

3. Letter, AVRADCOM, DRDAV-DI, 21 August 1979, subject: Advance Test Plan, *Preliminary Airworthiness Evaluation of the AH-1 Advanced (OGEE) Tip Shape Rotor Blades,* USAAEFA Project 77-25.

4. Technical Manual, TM 55-1520-236-10, *Operator's Manual, Army Model AH-1S Helicopter,* 17 November 1976.

5. Technical Data Package for Main Rotor Blade Assembly K747-033-1 TDPR1397.

6. Message, AVRADCOM, DRDAV-DI, 131930Z March 1980, subject: Test Plan, Preliminary Airworthiness Evaluation of the AH-1S Advanced (OGEE) Tip Shape Rotor Blades, USAAEFA Project 77-25.

7. Letter, AVRADCOM, DRDAV-DI, 17 October 1979, (with revisions 19 October, 4 December 1979, and 27 March 1980), subject: Airworthiness Release for Airworthiness Evaluation (PAE) of the AH-1 Advanced OGEE Tip Shape Rotor Blades, USAAEFA Project No. 77-25.

8. Final Report, USAAEFA, Project No. 77-38, *Production Validation Test-Government, Kaman K747 Improved Main Rotor Blade,* to be published.

9. Final Report, US Army Aviation Test Activity (USAAVNTA) Project No. 66-06, *Engineering Flight Test AH-1G Helicopter (Hueycobra), Phase D, Part 2, Performance,* April 1970.

APPENDIX B. AIRCRAFT DESCRIPTION

GENERAL

1. The test helicopter, S/N 76-22573, was a production AH-1S.The AH-1S main rotor mast and hub assembly had been replaced with a mast and hub assembly from an AH-1G. The AH-1G hub was instrumented for structural loads measurements at several locations, and the mast incorporated wiring and slip rings to transmit loads information from the rotor and hub to the data systems.

MAIN ROTOR BLADES

2. The tests were conducted with two sets of main rotor blades, the K747 blades and K747 blades modified with OGEE-shaped tips. The K747 blade tip weights were removed to facilitate installation of the OGEE tips. The OGEE blades therefore, had much lower rotational inertia than the K747 blades.

3. The blades utilize a multicell filament wound fiberglass spar, a nomex honeycomb core afterbody, and a Kevlar trailing edge spline, all enclosed by fiberglass skin. At the inboard end, cheekplates carry blade loads to an aluminum adapter which is attached to the hub with a pin.

4. The K747 blade airfoil shape is based on a family of airfoils developed by Boeing Vertol. To incorporate the OGEE-shaped tip, the outer 15% of the K747 blade was replaced by the OGEE tip (Fig 1). The airfoil shape varies from blade tip to root as follows:

r/R (Blade Radius Station)	Airfoil Design
From tip to 0.85	(K747) 8% thick Boeing Vertol VR-8
From 0.85 to 0.67	Linear Transition to 12% thick Boeing Vertol VR-7
From 0.67 to 0.25	12% thick Boeing Vertol VR-7
From 0.25 to 0.18	Gradual buildup to 25% thick by cheekplates

ENGINE AND TRANSMISSION/TAIL ROTOR DRIVE

5. The T53-L-703 turboshaft engine is installed in the AH-1S helicopter. This engine employs a two-stage, axial-flow free power turbine; a separate two-stage, axial-flow turbine driving a five-stage axial and one-stage centrifugal compressor; variable inlet guide vanes; and an external annular combustor. A 3.2105:1 reduction gear box located in the air inlet housing reduces power turbine speed to a nominal output shaft speed of 6600 RPM at 100 percent N_2. The engine reduction gear box is limited to 1175 foot pounds (ft-lb) torque for 30 minutes and to 1110 ft lb torque for continuous operation. A T_7 interstage turbine temperature sensor harness measures interstage turbine temperatures and displays this information in the cockpit as turbine gas temperature on the cockpit instruments.

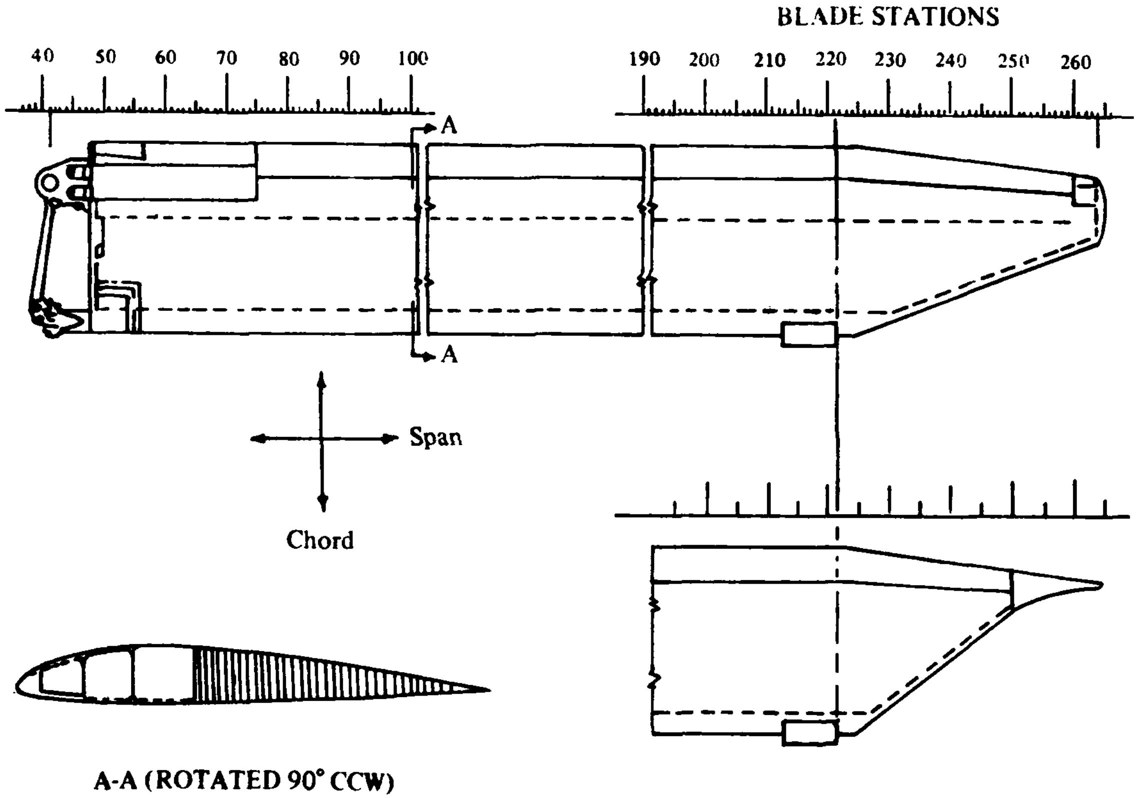


FIGURE 1
K747 - 003 IMPROVED MAIN ROTOR BLADE
AND OGEE TIP SHAPE

6. The main transmission has a 1290 SHP limit for 30 minutes and a 1134 SHP limit for continuous operation at a rotor speed of 324 RPM (100 percent N_R). The aircraft is further limited to 88% torque above 100 knots indicated airspeed (KIAS). The tail rotor drive system has a 260 SHP transient limit for 4 seconds and a 187 SHP limit for continuous operation. The engine used during this test had serial number LE 13145Z.

PRINCIPAL DIMENSIONS

7. The principal dimensions and general data concerning the AH-1S helicopters are as follows:

Overall Dimensions

Length, rotor turning	53 ft, 1 in (K747) 53 ft, 1.35 in (OGEE)
Height, tail rotor vertical	13 ft, 9.0 in
Length, rotors removed	44 ft, 7 in

Main Rotor	K747	OGEE
Diameter	44 ft	44 ft, 0.7 in
Disc area	1520.5 ft^2	1524.6 ft^2
Number of blades	2	2
Blade chord	See Figure 1	See Figure 1
Blade twist	-0.556 deg/ft	-0.556 deg/ft
Airfoil	See paragraph 2	See paragraph 2

Tail Rotor

Diameter	8 ft, 6 in
Disc area	56.75 ft^2
Solidity	0.1436
Number of blades	2
Blade chord, constant	11.5 in
Blade twist	0.0 deg/ft
Airfoil	NACA 0018 at the blade root changing linearly to a special cambered section at 8.27 percent of the tip

Fuselage

Length:	44 ft, 7 in
Height:	
To tip of tail fine	10 ft, 8 in
Ground to top of mast	12 ft, 3 in
Ground to top of transmission fairing	10 ft, 2 in

Width:

Fuselage only	3 ft
Wing span	10 ft, 9 in
Skid gear tread	7 ft

Elevator:

Span	6 ft, 11 in
Airfoil	Inverted Clark Y

Vertical Fin:

Area	18.5 ft^2
Airfoil	Special cambered
Height	5 ft, 6 in

Wing:

Span	10 ft, 9 in
Incidence	17 deg
Airfoil (root)	NACA 0030
Airfoil (tip)	NACA 0024

8. A flight control rigging check performed in accordance with procedures outlined in TM 55-1520-234-20 demonstrated that the cyclic collective pitch, and directional controls, and the elevator were within presecribed limits. The swashplate angles measured with respect to aircraft axes and tail rotor blade pitch angles are as follows:

SWASHPLATE ANGLES

Control Position	Lateral Angle	Longitudinal Angle
Neutral	1.5 deg L down	1.0 deg nose up
Full Forward	5.0 deg R down	10.0 deg nose down
Full AFT	5.0 deg R down	12.5 deg nose up
Full Right	7.0 deg R down	4.5 deg nose up
Full Left	7.5 deg L down	3.5 deg nose down

TAIL ROTOR BLADE PITCH ANGLES

Pedal Position	Blade Angle
Full Left	19.9 deg
Full Right	-11.0 deg

Weight and Balance

9. The aircraft weight, longitudinal center-of-gravity (cg) location and lateral cg location were determined prior to testing and checked periodically throughout the tests. A fuel cell calibration was also performed prior to testing. All weighings were accomplished with instrumentation installed without external stores or chin turret weapons installed.

10. The fuel loading for each test flight was determined prior to engine start and following engine shutdown by using a calibrated external sight gage to determine fuel volume and by measuring the fuel specific gravity. Fuel used in flight was recorded by a sensitive fuel-used system and verified with the pre- and postflight sight gage readings.

APPENDIX C. INSTRUMENTATION

1. The test instrumentation system was installed, calibrated, and maintained by USAAEFA. Data were obtained from calibrated instrumentation and recorded on magnetic tape and/or displayed in the cockpit. The digital instrumentation system consisted of various transducers, signal conditioning units, a 10-bit PCM encoder, with a sample rate of 200 samples per second, and a magnetic tape recorder. The data were also telemetered to a ground station for monitoring/test control. Time correlation was accomplished with pilot/engineer event switches, and on-board recorded and displayed Inter Range Instrumentation Group (IRIG) B time. Additionally, during the acoustics measurement flights, a "beep" tone was transmitted once per main rotor revolution from the AH-1S to the Y0-3A over an FM radio frequency. The tone was generated when one main rotor blade was at the 82.75 degree azimuth position (measured from the nose in the direction opposite to rotor rotation).

2. Cockpit displayed parameters and special equipment are listed below:

<u>Pilot Station</u>

Pressure altitude (boom)
Pressure altitude (ship)
Airspeed (boom)
Airspeed (ship)
Main rotor speed
Engine torque
Engine turbine gas temperature
Engine gas producer speed
Angle of sideslip
Event switch
Tether cable angles (longitudinal and lateral)

<u>Copilot/Engineer Station</u>

Airspeed (boom)
Altitude (boom)
Main rotor speed
Engine torque
Engine gas producer speed
Total air temperature
Fuel used
Cable tension
Time code display
Event switch
Data system controls

3. Parameters recorded on magnetic tape were as follows:

<u>PCM Parameters</u>

Time code
Event
Flight number

Run number
Main rotor speed
Fuel temperature
Fuel used
Engine fuel flow rate
Engine gas producer speed
Engine power turbine speed
Airspeed (boom)
Altitude (boom)
Total air temperature
Angle of attack
Angle of sideslip
Tether cable tension
Tether cable angle (longitudinal and lateral)
Engine torque
Engine exhaust gas temperature
Control positions
- Longitudinal cyclic
- Lateral cyclic
- Pedal
- Collective

Aircraft attitudes
- Pitch
- Roll

Aircraft angular velocities
- Pitch
- Roll
- Yaw

Center-of-gravity accelerations
- Vertical
- Lateral
- Longitudinal

Main rotor hub flapwise bending moment
- At station 5 (both blades)
- At station 8 (both blades)
- At station 11 (one blade)
- At station 20 (one blade)
- At station 37 (one blade)
- At station 68 (one blade)

Main rotor pitch link axial load
Main rotor drag brace axial load (both blades)
Main rotor shaft torque
Main rotor blade angle

APPENDIX D. TEST TECHNIQUES AND DATA ANALYSIS METHODS

GENERAL

1. Helicopter performance test data were generalized by use of nondimensional coefficients. The purpose of this generalization was to accurately predict performance at aircraft gross weight/ambient air condition combinations not specifically tested. The following coefficients were used:

a. Coefficient of power (C_P):

$$C_P = \frac{SHP \times 550}{\rho A (\Omega R)^3} \tag{1}$$

b. Coefficient of thrust (C_T):

$$C_T = \frac{GW}{\rho A(\Omega R)^2} \tag{2}$$

c. Advance ratio (μ):

$$\mu = \frac{1.6878 \times V_T}{\Omega R} \tag{3}$$

d. Advancing tip mach number (M_{TIP}):

$$M_{TIP} = \frac{1.6878\ V_T + \Omega R}{a} \tag{4}$$

Where:

SHP = Engine output shaft horsepower

550 = Conversion factor (ft-lb/sec/SHP)

ρ = Air density (slugs/ft^3)

A = Main rotor disc area (ft^2)

Ω = Main rotor angular velocity (rad/sec)

R = Main rotor radius

GW = Gross weight (lb)

1.6878 = Conversion factor (ft/sec/kt)

V_T = True airspeed (kt)

a = Speed of sound (ft/sec)

2. Engine output SHP was determined from the engine torque pressure. Torque pressure as a function of the power output of the engine was obtained from the engine manufacturer's test cell calibration. Horsepower was determined by the following equation:

$$SHP = \frac{N \times GR \times T_q}{63025} \tag{5}$$

Where:

N = Main rotor speed (RPM)

GR = Engine to main rotor gear ratio = 20.38362

T_q = Engine output shaft torque (in-lb)

63025 = Conversion factor (in-lb rev/min/SHP)

3. Shaft horsepower available and specification fuel flow were obtained from Lycoming Model Specification T53-L-703 (LTCJK-4G) Mo. 104-43 by using computer program file number LS19.04.32.00 dated 1 May 1974 and the inlet characteristics described in Reference 9, Appendix A.

HOVER PERFORMANCE

4. The tethered method of hover performance testing was used. This method required that the aircraft be at a very light gross weight, that it be tied to the ground by a 100-foot cable, and that a load cell be used to measure cable tension. During the test, the cable was kept taut and vertical at all times. To get a maximum variation of C_T (equation 2), rotor speed and cable tension were varied during the test. The technique used to vary cable tension was to set various torque settings from minimum required to hover out-of-ground effect (OGE) to the maximum allowed at the test conditions. Cable angle was displayed to the pilot in the cockpit in order to maintain the aircraft directly over the ground tie-down point.

5. The data were plotted as C_P versus C_T using equations 1 and 2. The gross weight in equation 2 was determined by adding cable tension to the engine start gross weight, and then subtracting the weight of the fuel burned prior to each data point. The data points obtained with the OGEE tip-shape blades were then fitted with a curve using a multiple linear regression program. The equation of the resulting line is:

$$C_P = 0.000126 + 0.495915\, C_T^{3/2} + 1203.1898\, C_T^{3} \tag{6}$$

This equation is valid only for the range of C_T actually tested and should not be used to extrapolate to higher or lower values of C_T.

LEVEL FLIGHT PERFORMANCE

6. Each level flight performance flight was designed to obtain one curve of C_p versus μ at a constant value of C_T. The flight technique was to stabilize at zero sideslip at incremental airspeeds from approximately 40 KIAS to the maximum attainable. Torque, altitude, airspeed, and rotor speed were held constant at each airspeed for at least 1 minute prior to recording data. Altitude was increased between data points as a function of fuel burnoff in order to maintain a constant ratio of gross weight to air pressure ratio (GW/δ). Also, rotor speed (N) was varied as a function of ambient air temperature in order to maintain a constant ratio of rotor speed to square root of the air temperature ratio ($N/\sqrt{\theta}$). By rearranging equation 2 as follows:

$$C_T = \frac{GW/\delta}{\rho_o A \left(\frac{2\pi R}{60}\right)^2 \left(\frac{N}{\sqrt{\theta}}\right)^2} \tag{7}$$

it can be seen that C_T will also be constant if GW/δ and $N/\sqrt{\theta}$ are constant. During these tests, the target GW/δ was different for each flight in a given aircraft configuration, but the target $N/\sqrt{\theta}$ was 324 RPM for all flights. The reason for maintaining constant $N/\sqrt{\theta}$ was to minimize the difference in compressibility effects between flights.

7. Airspeed and altitude were obtained from a boom-mounted pitot-static probe. Corrections for position error determined during Reference 8 testing were applied.

8. For the OGEE blade data, the C_p versus μ curves were cross plotted as C_p versus C_T with lines of constant μ. From these curves (Figs 3 through 5, App E) level flight performance at any combination of gross weight, rotor speed, pressure altitude, and air temperature can be determined

9. Measured (test) level flight power for both sets of rotor blades was corrected to the average dimensional (standard) conditions by assuming that the test dimensionless parameters, C_{P_t}, C_{T_t}, and μ_t are independent of atmospheric conditions. Consequently, the standard dimensionless parameters C_{P_s}, C_{T_s}, and μ_s are identical to C_{P_t}, C_{T_t}, and μ_t, respectively. From the definition of equation 1 the following relationship can be derived:

$$SHP_s = SHP_t \times \frac{\rho_s}{\rho_t} \times \left(\frac{\Omega_s}{\Omega_t}\right)^3 \tag{8}$$

Where:

t = Test day (measured)

s = Standard day (corrected)

For K747 blade data, a curve of C_p versus μ was obtained from Reference 8 at the appropriate value of C_T. The data was then corrected for a drag increase of

2.5 square feet. A similar correction for V_T could be derived from the definition of μ (equation 3). This correction was insignificant and therefore not made.

10. Specific range was calculated using measured values of V_T and fuel flow as follows:

$$NAMPP = \frac{V_T}{W_f}$$

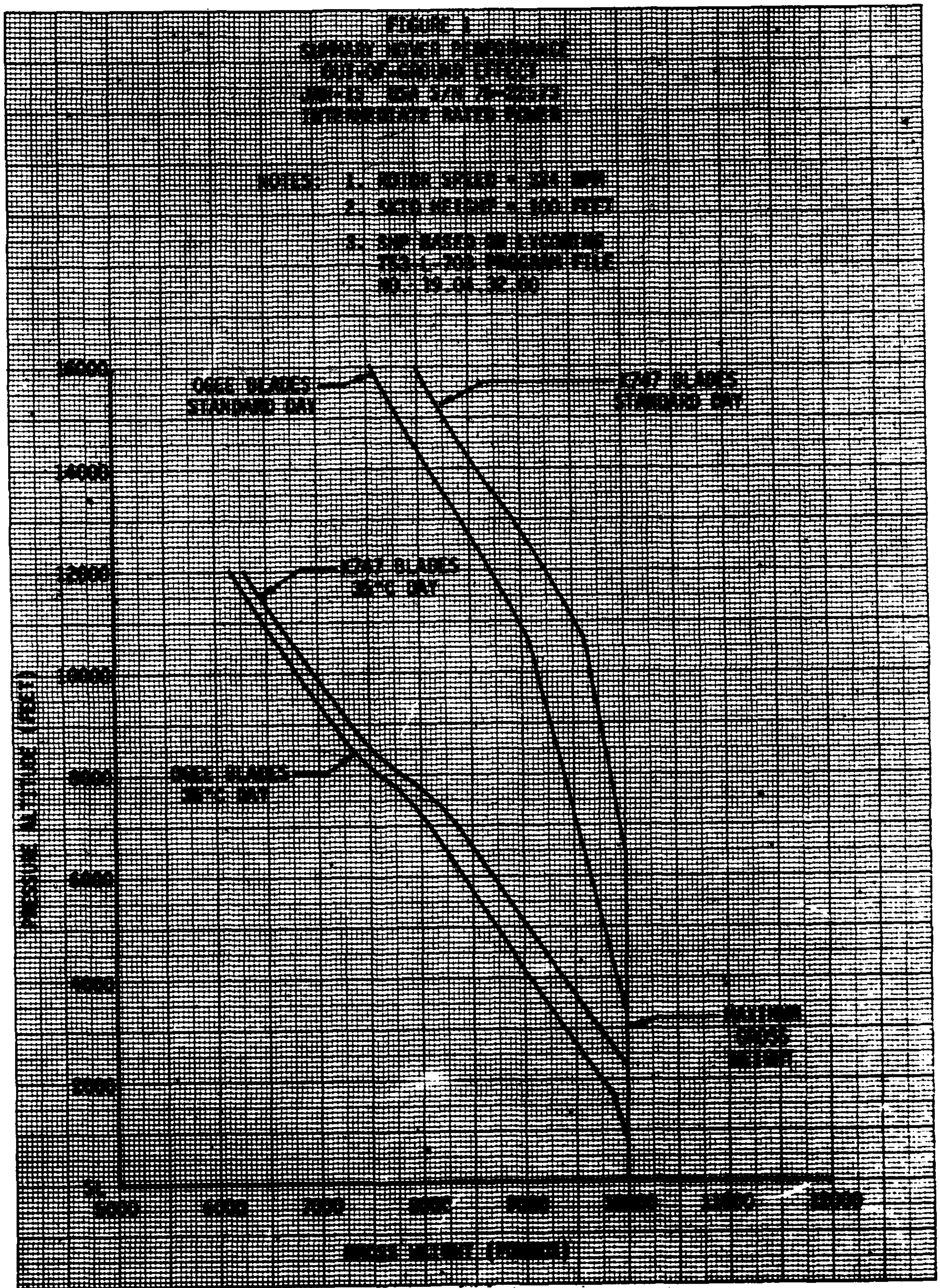
Where:

NAMPP = Specific range (nautical air miles per pound of fuel)

W_f = Fuel flow (lb/hr)

APPENDIX E. TEST DATA

INDEX



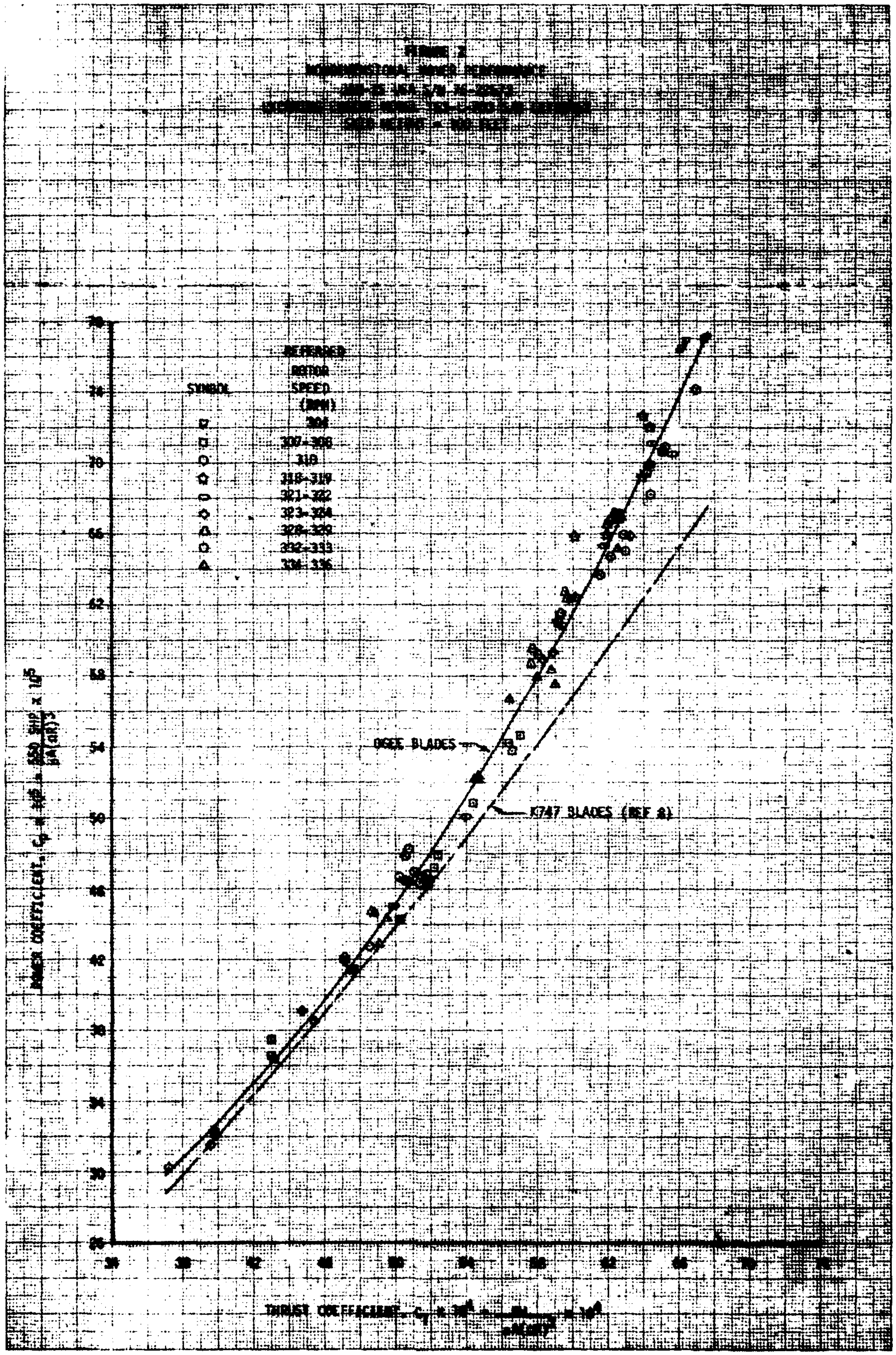

REFERRED
ROTOR
SPEED
SYMBOL
(RPM)
304
307-308
310
318-319
321-322
323-324
328-329
332-333
334-336
OGEE BLADES
K747 BLADES (REF 8)
POWER COEFFICIENT
THRUST COEFFICIENT

FIGURE 3
NONDIMENSIONAL LEVEL FLIGHT PERFORMANCE
JAH-1S USA S/N 76-22573

NOTES: 1. K747 BLADES WITH BARE TIPS
2. REFERRED ROTOR SPEED = 324 RPM
3. FORWARD LONGITUDINAL CG
4. CLEAN CONFIGURATION
5. CURVES DERIVED FROM FIGS. 6 THROUGH 8
6. ZERO SIDESLIP

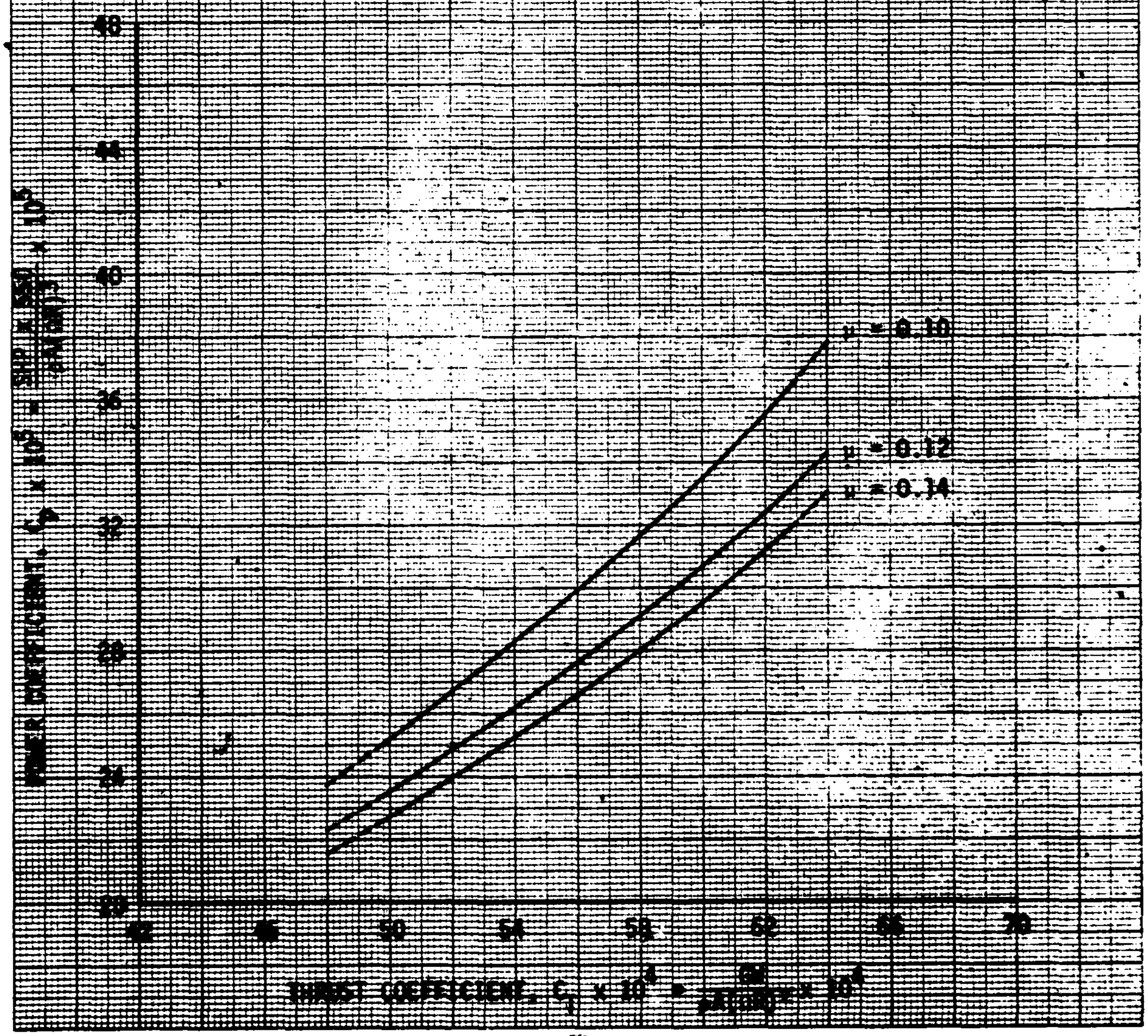
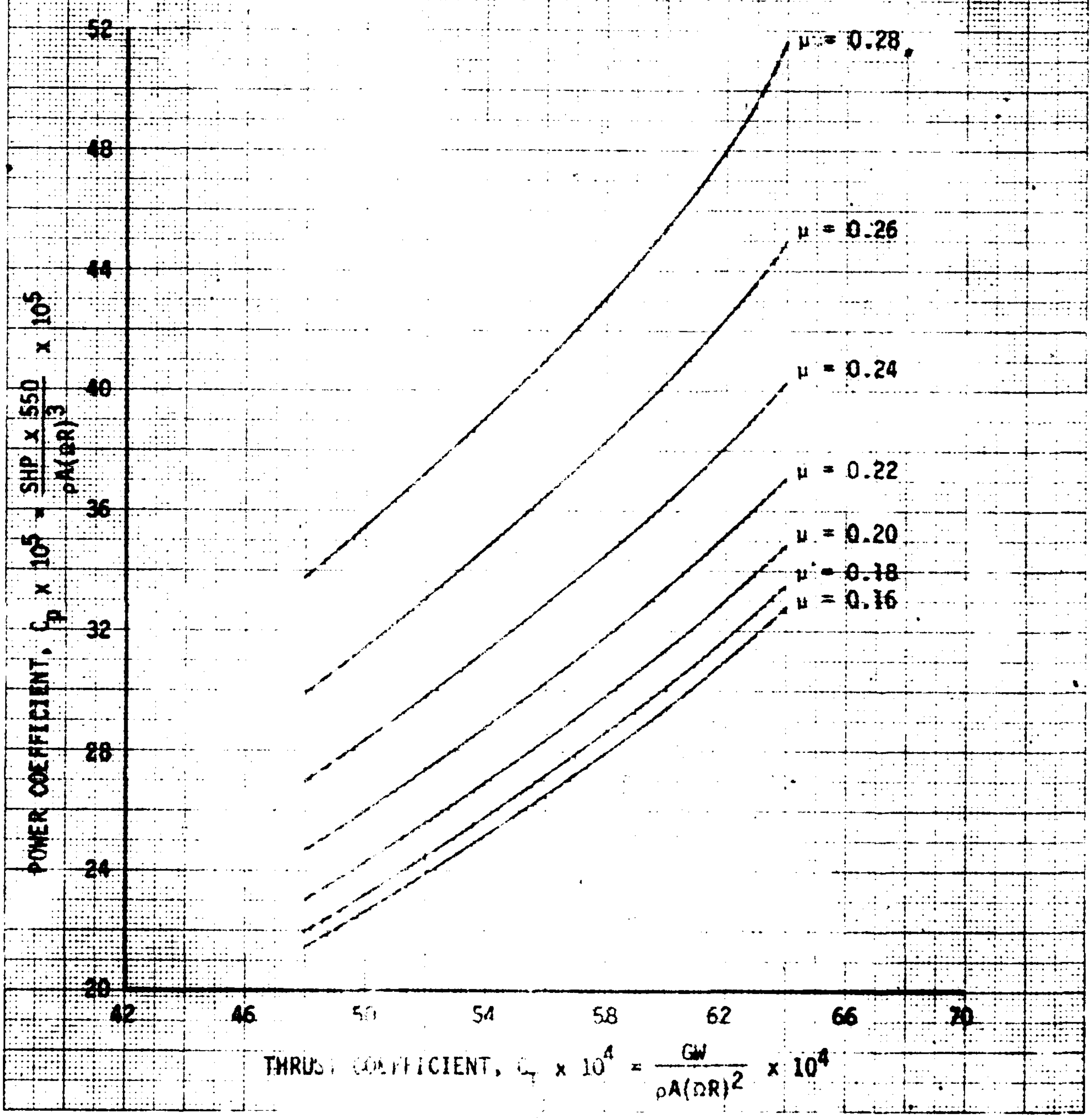


FIGURE 4
NONDIMENSIONAL LEVEL FLIGHT PERFORMANCE
JAH-1S USA S/N 76-22573

NOTES: 1. K747 BLADES WITH OGEE TIPS
2. REFERRED ROTOR SPEED = 324 RPM
3. FORWARD LONGITUDINAL CG
4. CLEAN CONFIGURATION
5. CURVES DERIVED FROM FIGS. 6 THROUGH 8
6. ZERO SIDESLIP



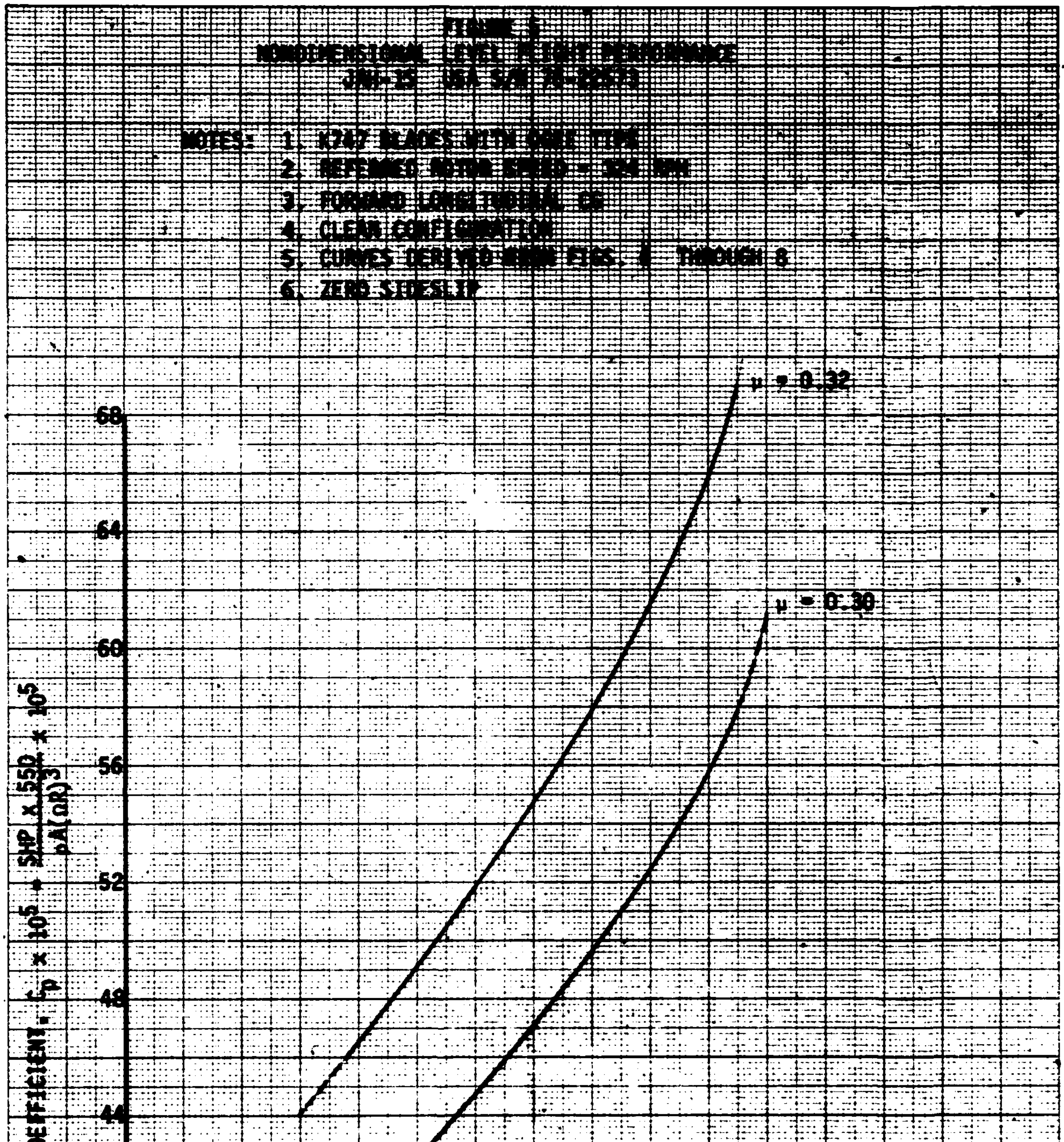


FIGURE 5
NONDIMENSIONAL LEVEL FLIGHT PERFORMANCE
NOTES:
3. FORWARD LONGITUDINAL CG
4. CLEAR CONFIGURATION
6. ZERO SIDESLIP
μ = 0.32
μ = 0.30
68
64
60
56
52
48
44
40
36
42
46
50
54
58
62
66
70
POWER COEFFICIENT, $C_P \times 10^5 = \frac{SHP \times 550}{\rho A(\Omega R)^3} \times 10^5$
THRUST COEFFICIENT, $C_T \times 10^4 = \frac{GW}{\rho A(\Omega R)^2} \times 10^4$

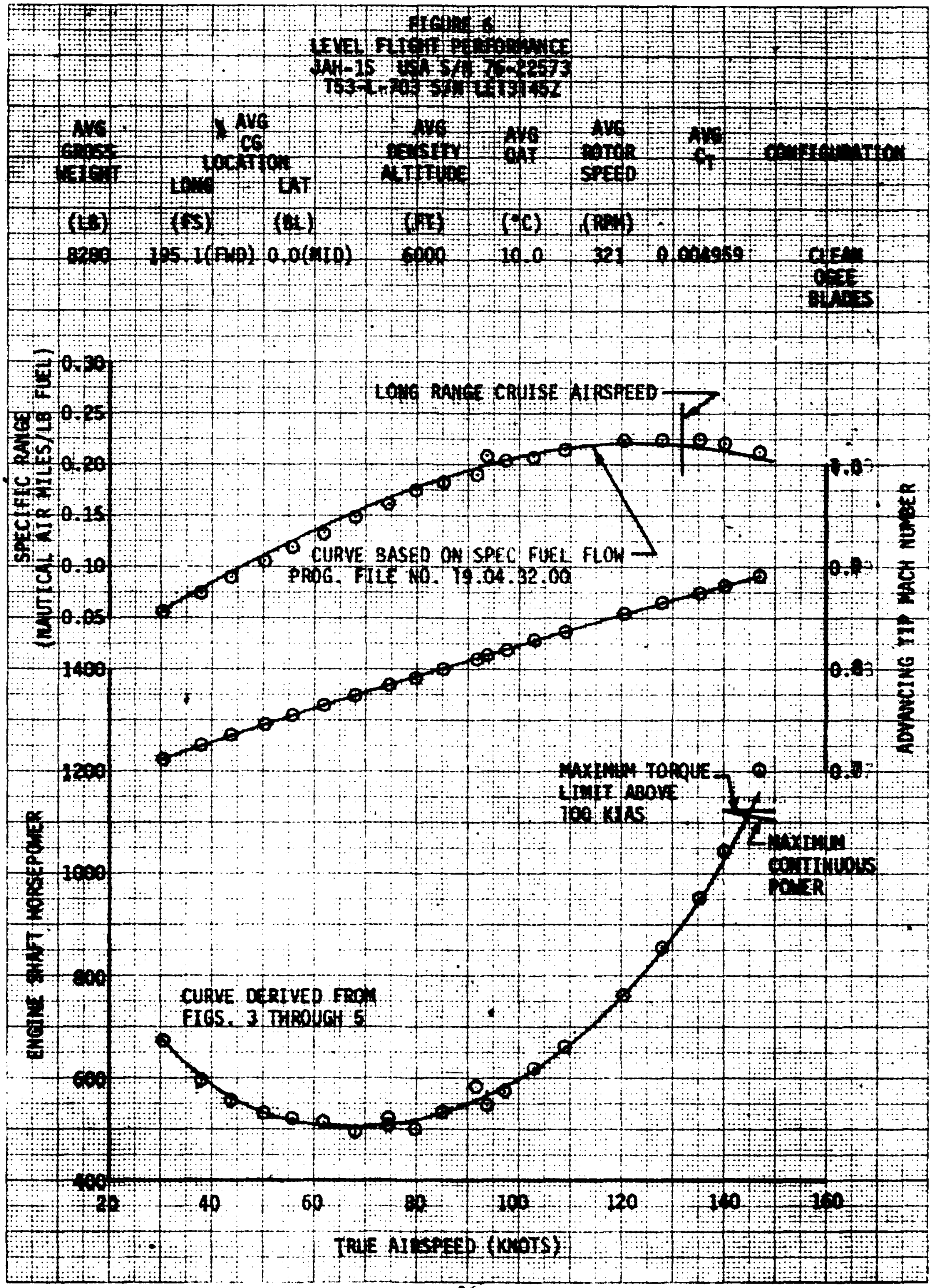
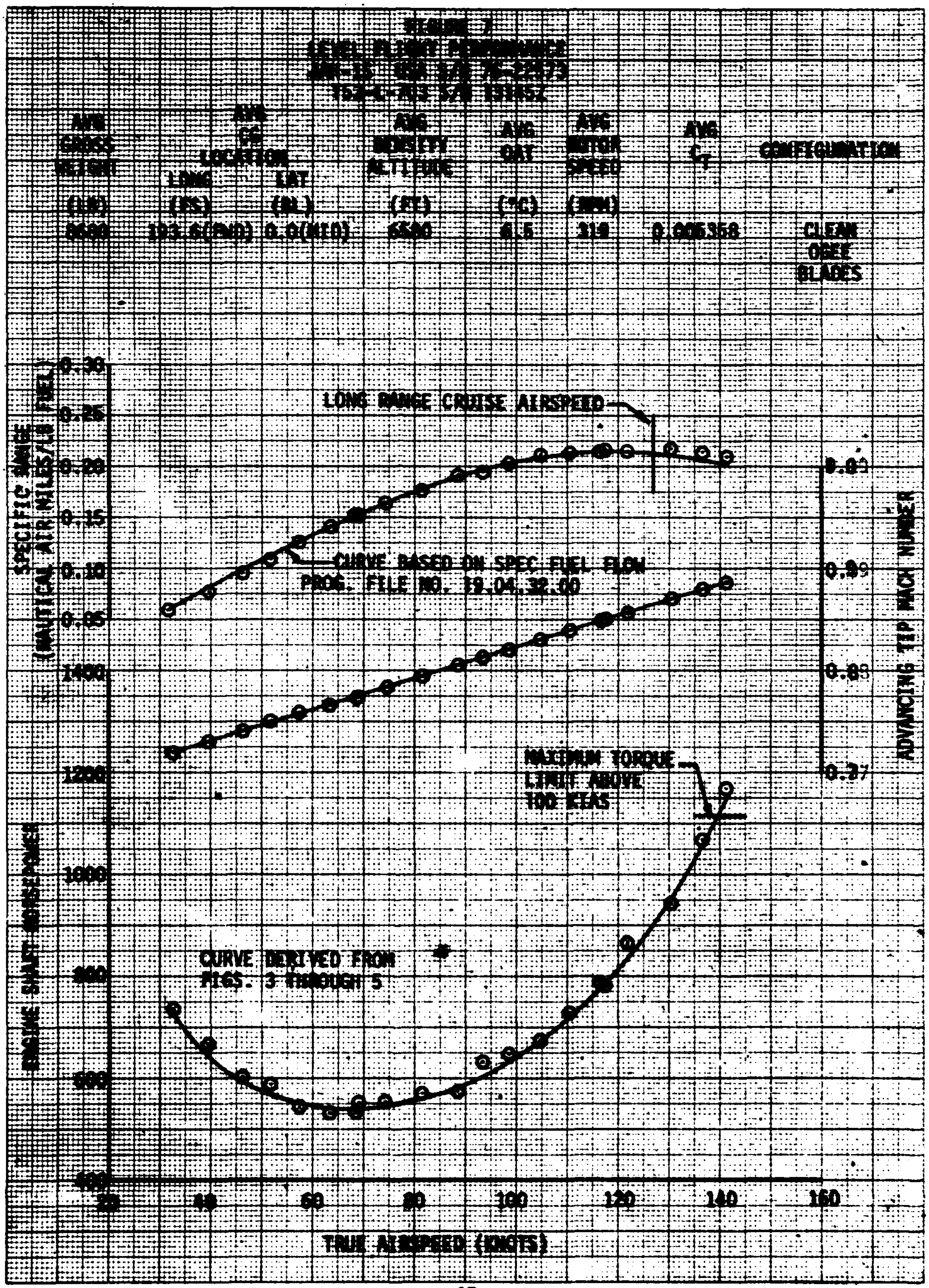
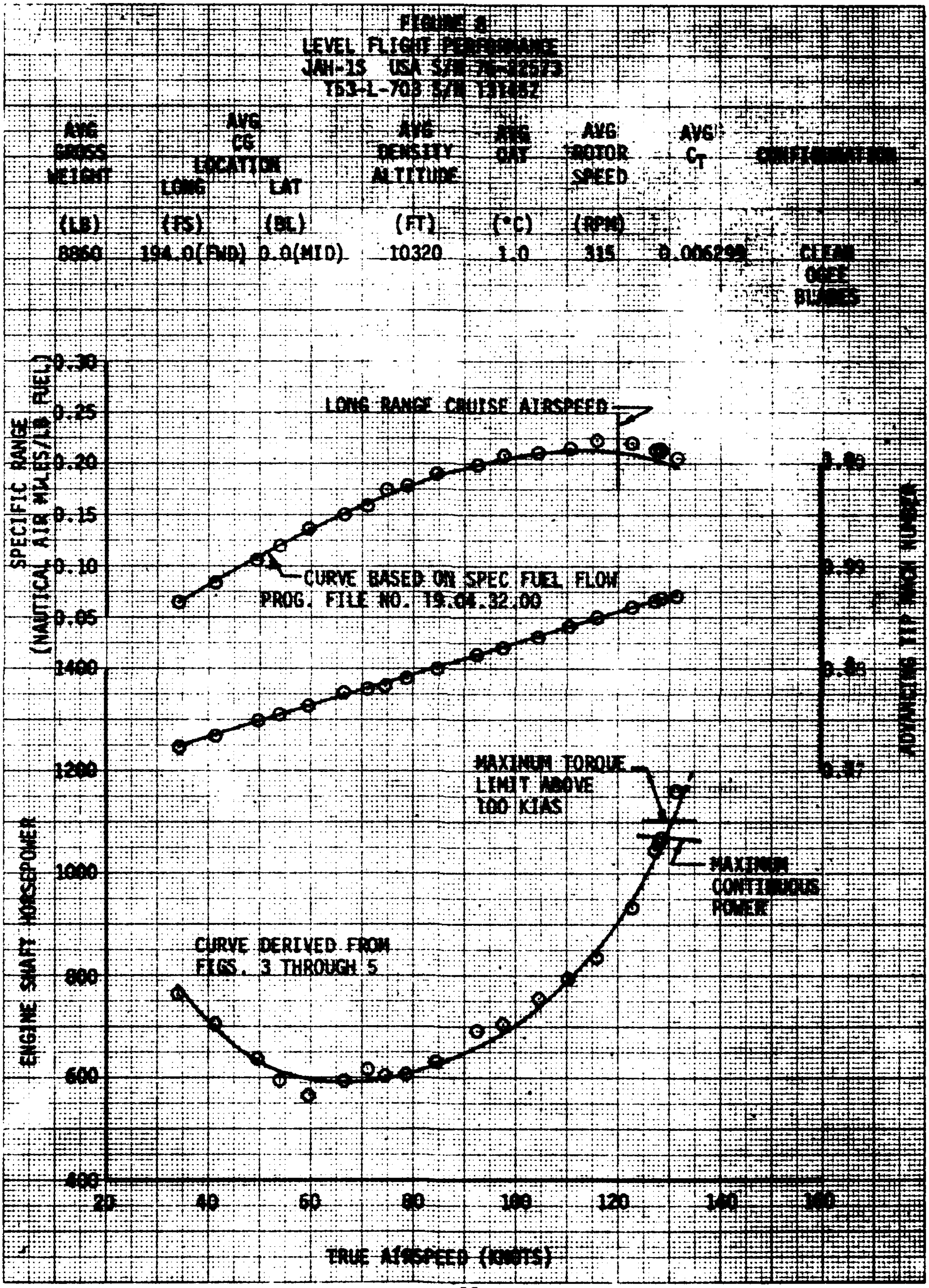


FIGURE 6
LEVEL FLIGHT PERFORMANCE
JAH-1S USA S/N 76-22573
T53-L-703 S/N LE13145Z
AVG GROSS WEIGHT (LB) 8200
% AVG CG LOCATION LONG (FS) 195.1(FWD)
LAT (BL) 0.0(MID)
AVG DENSITY ALTITUDE (FT) 6000
AVG OAT (°C) 10.0
AVG ROTOR SPEED (RPM) 321
AVG C_T 0.004959
CONFIGURATION CLEAN OGEE BLADES
LONG RANGE CRUISE AIRSPEED
CURVE BASED ON SPEC FUEL FLOW
PROG. FILE NO. 19.04.32.00
MAXIMUM TORQUE LIMIT ABOVE 100 KIAS
MAXIMUM CONTINUOUS POWER
CURVE DERIVED FROM FIGS. 3 THROUGH 5
SPECIFIC RANGE (NAUTICAL AIR MILES/LB FUEL)
ENGINE SHAFT HORSEPOWER
ADVANCING TIP MACH NUMBER
TRUE AIRSPEED (KNOTS)


AVG
CONFIGURATION
CLEAN
OGEE
BLADES
LONG RANGE CRUISE AIRSPEED
CURVE BASED ON SPEC FUEL FLOW
PROG. FILE NO. 19.04.32.00
MAXIMUM TORQUE
LIMIT ABOVE
100 KIAS
CURVE DERIVED FROM
FIGS. 3 THROUGH 5
SPECIFIC RANGE
(NAUTICAL AIR MILES/LB FUEL)
ENGINE SHAFT HORSEPOWER
ADVANCING TIP MACH NUMBER
TRUE AIRSPEED (KNOTS)
0.30
0.25
0.20
0.15
0.10
0.05
1400
1200
1000
800
600
400
20
40
60
80
100
120
140
160


LEVEL FLIGHT PERFORMANCE
JAH-1S
T53-L-703
AVG GROSS WEIGHT (LB)
AVG CG LOCATION LONG (FS) LAT (BL)
AVG DENSITY ALTITUDE (FT)
AVG ROTOR SPEED (RPM)
AVG C_T
8860
194.0(FWD)
0.0(MID)
10320
1.0
315
0.006298
CLEAN
SPECIFIC RANGE (NAUTICAL AIR MILES/LB FUEL)
0.30
0.25
0.20
0.15
0.10
0.05
LONG RANGE CRUISE AIRSPEED
CURVE BASED ON SPEC FUEL FLOW
PROG. FILE NO. 19.04.32.00
ENGINE SHAFT HORSEPOWER
1400
1200
1000
800
600
400
MAXIMUM TORQUE
LIMIT ABOVE
100 KIAS
MAXIMUM
CONTINUOUS
POWER
CURVE DERIVED FROM
FIGS. 3 THROUGH 5
ADVANCING TIP MACH NUMBER
20
40
60
80
100
120
140
160
TRUE AIRSPEED (KNOTS)

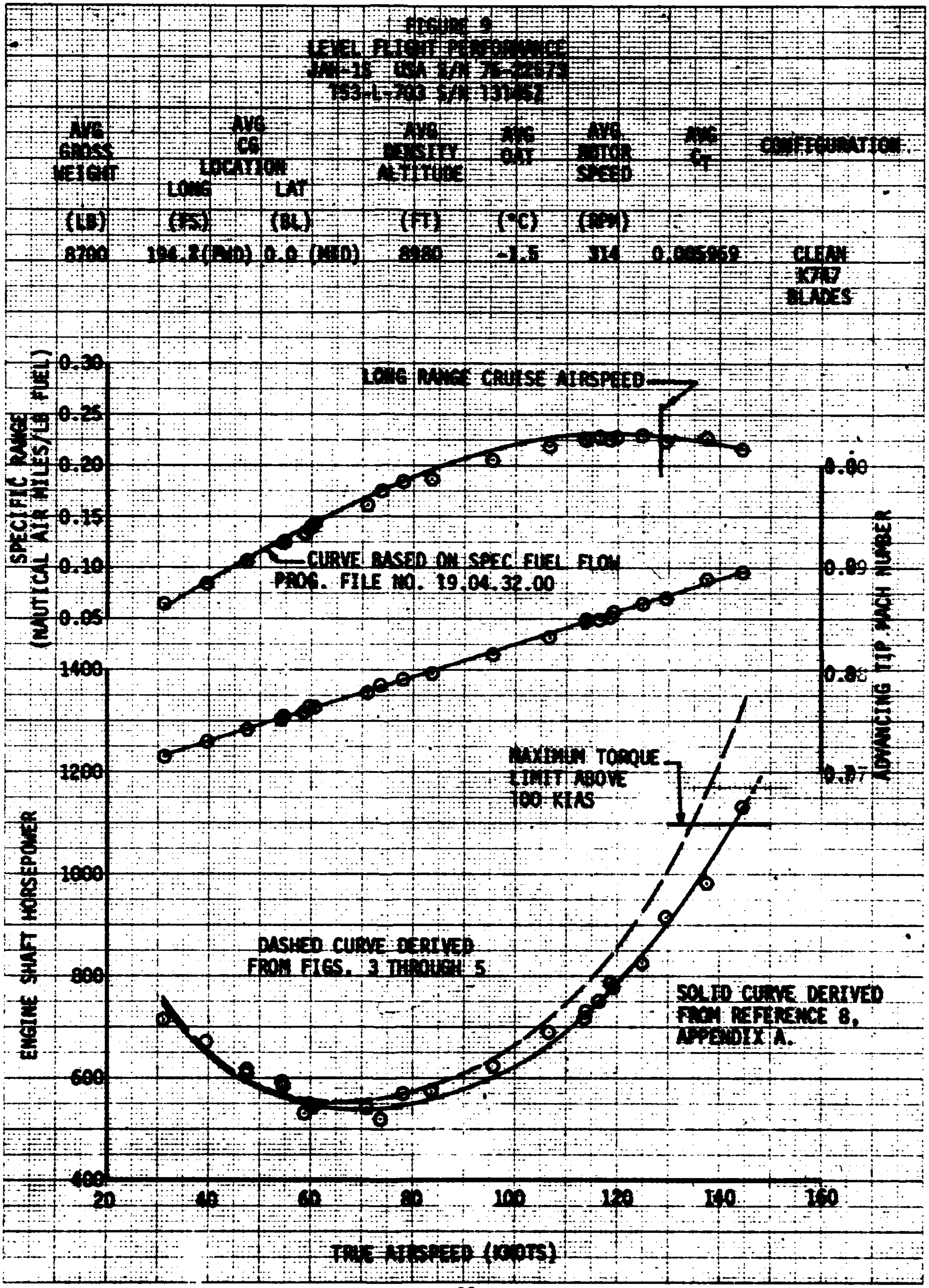


FIGURE 9
LEVEL FLIGHT PERFORMANCE
JAH-1S USA S/N 76-22573
T53-L-703 S/N 13145
AVG GROSS WEIGHT (LB) 8700
AVG CG LOCATION LONG (FS) 194.2(MID)
LAT (BL) 0.0 (MID)
AVG DENSITY ALTITUDE (FT) 8980
AVG OAT (°C) -1.5
AVG ROTOR SPEED (RPM) 314
AVG C_T 0.005969
CONFIGURATION CLEAN K747 BLADES
LONG RANGE CRUISE AIRSPEED
CURVE BASED ON SPEC FUEL FLOW
PROG. FILE NO. 19.04.32.00
SPECIFIC RANGE (NAUTICAL AIR MILES/LB FUEL)
ADVANCING TIP MACH NUMBER
MAXIMUM TORQUE LIMIT ABOVE 100 KIAS
DASHED CURVE DERIVED FROM FIGS. 3 THROUGH 5
SOLID CURVE DERIVED FROM REFERENCE 8, APPENDIX A.
ENGINE SHAFT HORSEPOWER
TRUE AIRSPEED (KNOTS)

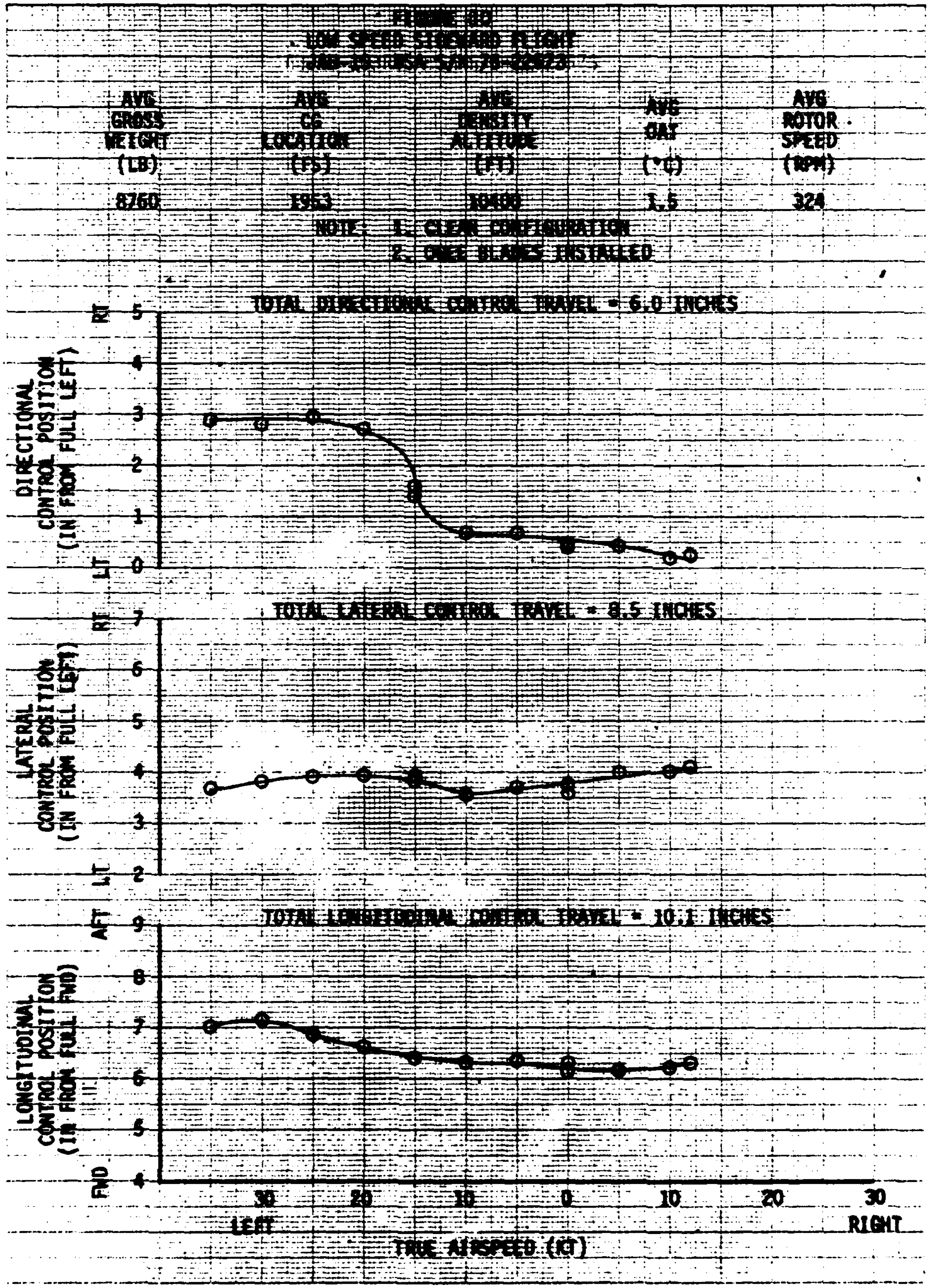
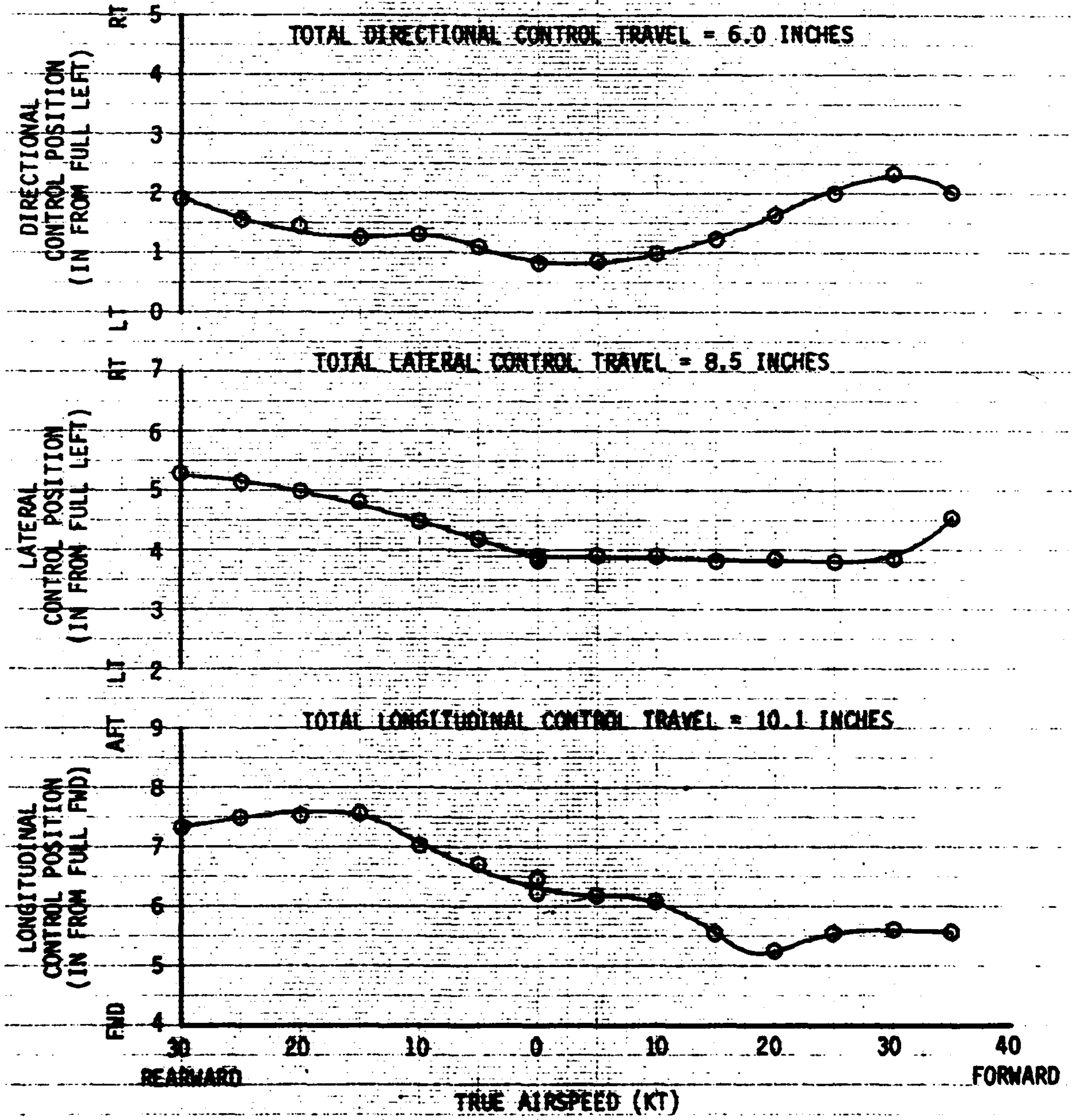


FIGURE [illegible]
LOW SPEED SIDEWARD FLIGHT
(AH-1G USA S/N 70-[illegible])
AVG GROSS WEIGHT (LB)
AVG CG LOCATION (FS)
AVG DENSITY ALTITUDE (FT)
AVG OAT (°C)
AVG ROTOR SPEED (RPM)
8760
195.3
10400
1.5
324
NOTE: 1. CLEAN CONFIGURATION
2. OGEE BLADES INSTALLED
TOTAL DIRECTIONAL CONTROL TRAVEL = 6.0 INCHES
DIRECTIONAL CONTROL POSITION (IN FROM FULL LEFT)
RT
LT
TOTAL LATERAL CONTROL TRAVEL = 8.5 INCHES
LATERAL CONTROL POSITION (IN FROM FULL LEFT)
TOTAL LONGITUDINAL CONTROL TRAVEL = 10.1 INCHES
LONGITUDINAL CONTROL POSITION (IN FROM FULL FWD)
AFT
FWD
LEFT
RIGHT
TRUE AIRSPEED (KT)

FIGURE 11
LOW SPEED FORWARD AND REARWARD FLIGHT
JAH-1S USA S/N 76-22573

AVG GROSS WEIGHT (LB)	AVG CG LOCATION (FS)	AVG DENSITY ALTITUDE (FT)	AVG OAT (°C)	AVG ROTOR SPEED (RPM)
8220	194.7	10640	3.5	324

NOTE: 1. CLEAN CONFIGURATION
2. OGEE BLADES INSTALLED



DISTRIBUTION

Assistant Secretary of the Army (R&D)	1
Deputy Chief of Staff for Logistics (DALO-SMM)	1
Deputy Chief of Staff for Operations (DAMO-RQ)	1
Deputy Chief of Staff for Personnel (DAPE-HRS)	1
Deputy Chief of Staff for Research Development and Acquisition (DAMA-PPM-T, DAMA-RA, DAMA-WSA)	3
Comptroller of the Army (DACA-EA)	1
US Army Materiel Development and Readiness Command (DRCDE-DH, DRCQA-E, DRCRE-I, DRCDE-RT)	4
US Army Training and Doctrine Command (ATTG-U, ATCD-T, ATCD-ET, ATCD-B)	4
US Army Aviation Research and Development Command (DRDAV-DI, DRDAV-EE, DRDAV-EG)	10
US Army Test and Evaluation Command (DRSTS-CT, DRSTS-AD)	2
US Army Troop Support and Aviation Materiel Readiness Command (DRSTS-Q)	1
US Army Logistics Evaluation Agency (DALO-LEI)	1
US Army Materiel Systems Analysis Agency (DRXSY-R)	1
US Army Operational Test and Evaluation Agency (CSTE-POD)	1
US Army Armor Center (ATZK-CD-TE)	1
US Army Aviation Center (ATZQ-D-T, ATZQ-TSM-A, ATZQ-TSM-S)	3
US Army Combined Arms Center (ATZLCA-DM)	1
US Army Infantry Center (ATSH-TSM-BH)	1
US Army Systems Center (IGAR-TA, IGAR-Library)	2

DISTRIBUTION CONT.

US Army Research and Technology Laboratories/ Applied Technology Laboratory (DAVDL-ATL-D, DAVDL-Library)	2
US Army Research and Technology Laboratories/ Aeromechanics Laboratory (DAVDL-AL-D)	1
US Army Research and Technology Laboratories/ Propulsion Laboratory (DAVDL-PL-D)	1
US Army Troop Support and Aviation Materiel Readiness Command (DRCPM-CO-T)	1
Defense Technical Information Center (DDR)	12